The Ancient Merrimack

— IN —

APHELION WINTER.

THE

Ancient Merrimack and its Glaciers

—IN—

APHELION WINTER.

BY

SAMUEL D. LORD.

FOR THE NEW HAMPSHIRE BOARD OF AGRICULTURE.

CONCORD:
PRINTED BY THE REPUBLICAN PRESS ASSOCIATION.
1884.

THE ANCIENT MERRIMACK AND ITS GLACIERS IN APHELION WINTER.

Looking at the Merrimack river, we see its waters flow in a comparatively small channel, but at the same time the form of its banks and its several receding terraces, now level, now inclining, extending sometimes a mile on either side, satisfy us that at some time in its geological history its waters were made to flow over a greater space, under very different conditions from the present.

We have seen the current voraciously take away sand and soil from one side of the stream, and at the same time gently deposit the like on the other side, and we have seen river beds filled, the strata of sand and mud deposited one above the other, until after a few years they rise above the level of the stream and become permanent dry land, and vegetation grows thereon. The character of such formations is not unlike that of the river banks and terraces along the Merrimack, from its rise to the ocean. That these banks and terraces are the work of water, no one for a moment can question. But when we speak simply of the action of water in producing these formations, we are not satisfied to stop here, for our belief goes further, and we seek to know the causes of these phenomena.

In riding from Hooksett to Suncook, near the mills, southwesterly from the great clay banks, we may see a boulder of great proportions, weighing some hundred tons, bedded in the sand and clay of that place. It is a gneissic rock, and the sand and clay there could, under no ordinary transformation, form such a rock. It is in composition foreign to the place. Further north, near the railroad track, excavated from the sand, we see many other smaller boulders, of granitic formation. But such boulders are found everywhere in New Hampshire.

Whence came these boulders? Differing in composition from the surrounding sand or earth, we know they are not natives of the place: they are foreign to it, and were transported there by some force that has now ceased to exist.

The Secretary of the Board of Agriculture, in boring a well on his farm on the Merrimack river, beneath a few feet of interval soil came to clay, which he found to be some forty feet thick, and below this clay, at a depth of eighty-two feet, through successive layers of sand, clay, marl, and gravel (all being a sedimentary deposit), he reached a pebbly formation, the undoubted bed of the ancient river.

Now, the action of water under varied circumstances might produce these formations of the banks, terraces, and sedimentary deposits of clay and sand; but its action in this way does not account for the boulders we find. They do not swim in the water, but they are and can be transported on the ice, which may float in water: and here we come boldly to the suggestion of the floating ice, or more tardy glacier, in the valleys of the Merrimack and its tributaries.

At the first thought this suggestion may seem incredible, but we read of and see the glaciers in the Alps, and even nearer to us, in Greenland, and we know of their existence at the present time in nearly every lofty mountain; and when we see the marks, striæ, and scratches upon the highest rocks, and boulders scattered everywhere, which mark the tracks of the glacier or floating ice, and which the geologists follow with as much certainty as the hunter does the tracks of the deer, we are convinced there is no other true interpretation; and yet it is only a few years that we have dared to entertain such a thought.

Geologists have traced the river Rhone from its beginning, in the glacier at the foot of the Alps, to the Mediterranean. On this river is the celebrated Lake Geneva, fifty miles long and from two to eight miles wide; and we are told that this lake was scooped out by the glacier that once moved down that valley. Looking to the Switzerland of America, it is not incredible that our own Winnipiseogee was formed by the same force of the glacier, for the evidence is just as strong.

The Massabesic is surrounded by hills: the outlet is over a hard ledge, now worn down by the water and ice to its present level, that in glacial times was many feet higher. These reservoirs of the Winnipiseogee and Massabesic are the work of erosion,—once plains, and by the erosive force of water and ice dug out, and the mud and sand washed down the valley of the Merrimack, forming in part its banks and terraces of to-day. Such instances are common in all parts of the state, where the same forces have done like work, and left the evidences behind them in the form of lakes and ponds of all sizes.

The Yosemite valley was once filled with the glacier and floating ice; the great cañons of the Colorado were caused by the erosions of water in glacial times; and why have we not the indisputable right to say the cañon of the Merrimack shall be interpreted in the same way?

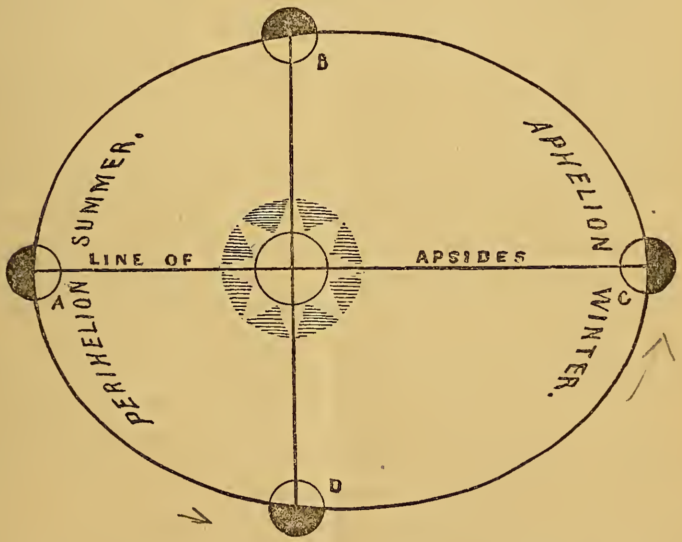
But, you will say, before we can have the ice and snow of the glacier we must have the temperature fit to produce it; and if this condition is established, no one can doubt.

Thousands of years ago, all admit there was an age of ice, and many men of science believe these glacial periods have occurred in all the different geological divisions, at times of high eccentricity. Mr. Croll, one of the best authorities on this subject, says that the glacial age must have occurred between 720,000 and 980,000 years ago, or between 80,000 and 240,000 years ago; and he further says, "on this point I consulted several eminent geologists, and they all agreed in referring the glacial epoch to the former period, the reason assigned being that they considered the latter period much too recent and of too short duration to represent that epoch." He however refers it to the latter. He might have referred to both, and others previous also. I do not propose to invite you in this paper to go back so far as those ages, but only some 12,000 years, where I hope to be able to find conditions fit for a New Hampshire glacier, and this by simple astronomical facts which we learn in our schools, that, if applied to our subject, must be apparent to all.

To begin, let me refer to some meteorological conditions and data which you may all know. The mean annual temperature of Concord is about 45°; north it will be lower, and south higher. I assume that the mean annual temperature of the state is now 45°. Since the freezing point is 32°, we have only to find a temperature averaging 13° below the present to represent one proper for snow and ice, in some parts at least, the year round. Snow now remains during nearly the whole year in some parts of the White Mountains, and it was particularly noticed in the summer of 1882, in some of the ravines there, very late. On the first of July, 1883, the snow in Tuckerman's ravine, in places, was fifty feet deep, and did not disappear till the first of August, and again appeared the 9th of September. But how shall we account for so low a temperature as we seek, necessary to produce a glacier? Is not the heat of the sun the same from year to year, equal in intensity? Did New Hampshire ever have a temperature in which snow remained for the whole year, and year after year accumulating, until it reached an altitude higher than Mt. Washington? How otherwise will you account for those scratches on the summit rocks, their channelling, the striæ, all parallel, pointing in one common direction, unless the glacier or ice sheet reached even higher, and in its movement, with rocks frozen in it, chiselled out the channels and grooves we find on the lofty mountain ledges and rocks? Prof. Dana claims that in northern New England the ice had a mean thickness of 6,500 feet, while between the St. Lawrence and Hudson's Bay it was not less than 12,000 feet.

There are three causes (astronomical) that I give as sufficient to produce such a climate: 1, the *precession* of the equinoxes; 2, the *obliquity* of the ecliptic; 3, the *eccentricity* of the ecliptic: and it will be observed that these all relate to the ecliptic—the orbit of the earth in its annual motion around the sun.

I will now discuss the *first*, *the precession of the equinoxes*. By "equinox" is meant "equal night," and there are two points on the line of the earth's annual motion where there are equal days and equal nights. They are those points where the sun, as we say in common language, "crosses the line." Now the exact point where the "sun crossed the line" in March, 1882, was not the point where he "crossed the line" in March, 1883. The difference between these two points is 50.44″, according to Stockwell, as given by him in the 18th vol. Smithsonian Contributions, &c. The point of crossing varies this amount annually to the west. By reducing the whole ecliptic of 360° to seconds, and dividing by 50.44″, we find the quotient nearly 25,694 years as the time required for completing the whole ecliptic, or the precession period. But while the equinoxes move to the west towards perihelion, the perihelion also moves towards the equinoctial about 12″ annually, so these two points are approaching each other by the sum of 50.44″ and 12″, or about $62\frac{1}{2}$″ annually;—and now again reducing the 360° of the ecliptic to seconds, and dividing by $62\frac{1}{2}$, we find the period is reduced from the 25,694 to about 21,000 years. This will be better understood by studying the diagram, which represents the positions of the earth and sun with reference to the ecliptic 12,000 years ago. But we must remember the positions at the present time are the reverse of those of 12,000 years ago, our present winter being in perihelion with the earth at A, moving in winter from B through A to D, and describing the arc D, C, B in summer.



The ecliptic, it will be seen, is represented an ellipse in form, the earth moving round the sun in the direction of A, D, C, B. We will consider the line of Apsides, A, C, as coincident with the equator.

Taking A as a starting-point, the earth will move on the ecliptic through D, C, B, and reach A, or rather a new equinoctial point 50.44″ west from A, towards B, in a year, and this equinoctial point at A will move annually this distance of 50.44″ towards B. This movement is called *precession*, because the point where the earth reaches the equinox *precedes* the previous year by this distance, and in time this point will recede to B, then to C. But again, the line of Apsides moves in a contrary direction, C towards B, 12″ annually, and we have seen that in about 10,500 or one half of 21,000 years, they will meet somewhere between C and B, moving over half of the ecliptic, the whole being some 21,000 years.

The line of Apsides, A, C, measures the distance between aphelion and perihelion;—being opposite each other, the movement of these points is consequent, of course, upon the movement of the ecliptic itself. This change of perihelion in reference to the motion of the earth is considered in the astronomical relations of the earth to the fixed stars, and the revolution of the earth from perihelion round to perihelion again is called the *anomalistic* year, four minutes longer than the equinoctial year. Looking forward, we find the earth in this movement, in the year 11,928, will be in aphelion in winter again, and most distant from the sun.

The seasons change with the change of the equinoxes. One fourth revolution gives winter for spring, and one half revolution gives winter for summer, and this is the change from perihelion to aphelion. This change of seasons from the perihelion to aphelion it is important to remember in reading this paper, since it is by reason of the transfer of the perihelion winter to aphelion winter that the climate we seek is to be found. The present winter in perihelion was 10,500 years ago in aphelion; the earth was, therefore, 3,000,000 of miles farther from the sun than at present, one thirtieth of the whole distance of the earth from the sun, and consequently colder.

In 1250, or 634 years ago, the solstice and perihelion were at the same point on the ecliptic, we are told by astronomers, and if we take that as the starting-point, 634 years of the present perihelion winter have passed, which, added to 10,500, gives us the date of the beginning of the last aphelion winter as about 12,000 years ago, hence we conclude we are approaching a colder period.

Summer is now eight days longer than winter, because in aphelion, so the aphelion winter is eight days longer than the perihelion summer; and taking the eight days from the perihelion summer and adding eight days to the aphelion winter makes a relative difference of sixteen days for the aphelion winter over the present.

We may, then, have some conception of such a winter. But the summer coming in perihelion must have been so much the warmer, and one would say warm enough to compensate for the cold of winter. This is true in theory; but a meteorological principle comes in here, viz., that the extra heat is cancelled or absorbed in converting the snow and ice of the previous winter to water, and in other ways; for the greater the extremes of heat and cold the greater and denser the clouds will be, the greater the heat applied to the boiler the greater will be the quantity of steam, and the summer of 12,000 years ago might for this reason, through the density of the clouds and the loss of heat in the great evaporation, be even colder than the present. Let us see an application of this in our present temperature. The sun, for a month before the September equinox and a month after the March equinox, is in the same relative position to the equator, and to us at the same angle and the same distance, and the same amount of heat is distributed over our zone; yet there was a mean difference of 21.64° in temperature in those times in 1883.

Mr. Meech, a writer on *Light and Heat*, referring to this subject, in high latitudes, says,—"According to Dr. Kane and others, a dense and lasting fog prevails after the middle through the rest of the summer season, and effectually prevents the rise of temperature, which the sun's intensity would otherwise produce." This is to be explained in the loss of heat in the work of evaporation, and reducing the snow and ice to water, producing fogs and clouds which intervene between the sun and the earth. This much for precession. I shall recur to this again, and be more particular as to the range of the thermometer in the aphelion winter we have found.

Some fifty years ago Adhemar, a French mathematician, recognizing the effect of the precession period on the climate, contended that periods of heat and cold followed each other every

10,000 years,—consequently ice and cataclysms succeeded each other accordingly; that the vast aggregations of ice at the North pole in aphelion winters, and its melting and floods in the approach of the perihelion winter, account for geological cataclysms of the past. It is not, however, advocated at present.

The second reason for a reduction of temperature 12,000 years ago was in consequence of the greater obliquity of the ecliptic at that period. By the obliquity of the ecliptic, astronomers mean the greater angle it forms with the equator; in other words, the further south the "sun goes," the greater obliquity of the ecliptic.

The sun in winter, at the solstitial point, is 23° 27½′ south of the equator, and this obliquity causes our winter, because the less vertical his rays are to the earth the less heat we have from the sun; and we are told by astronomers that the sun may go to a solstitial point 24½° south, or one degree more than now, and at about that period it did go south to that degree; and Stockwell finds that 8,000 years ago it did go to the southern solstitial point of 24¼°. The obliquity changes about 46 seconds of a degree per century.

On the basis of these figures, it was colder by this one degree of latitude of the sun further south by several degrees of the thermometer in northern latitudes. The sun, in his annual journey south, is four days in passing one degree of this obliquity, and he is also as many days returning, which adds eight days more to the aphelion winter of that period; and the same time being taken from the summer gives a relative difference of sixteen days more for that winter than at present. This difference must be allowed simply to the obliquity of the ecliptic at that time. We have, then, found thirty-two days more for the aphelion winter past than for the present winter.

I have said the earth was 3,000,000 of miles nearer the sun at perihelion than at aphelion. Now, at that period, 12,000 years ago, the distance was more than 3,000,000 by one half million nearly, according to Leverrier. We see, then, it was colder in consequence. This difference of one half million of miles in the eccentricity of the ecliptic is the third reason I have named for a cold period at that time.

This shrinkage of eccentricity, now amounting to one half million of miles since the aphelion winter, will continue till the earth's orbit will become nearly a circle, never, however, to reach a circle before the eccentricity will increase again, and so continue and produce in the distant future perhaps another ice period like those of 80,000 and 240,000 years ago. Two hundred thousand years ago the eccentricity was 10,500,000 miles, and 850,000 years ago it was 13,500,000, according to Leverrier, now only 3,000,000; and these are the periods to which Mr. Croll refers as the great glacial epochs I have named. Probably no man has ever given this subject more attention than Mr. Croll, and, as his conclusions are pertinent and in the direction of my argument, I will quote from him. "About 11,700 years ago," he says, "the northern winter solstice was in the aphelion. The eccentricity at that time was .0187, being somewhat greater than it is now, but the winters occurring in aphelion instead as now in perihelion, they would on that account be probably 10° or 15° colder than they are at the present day." But this was spoken of the English climate, modified then as now by the Gulf stream; and if we apply the doctrine of inverse squares, the reduction of temperature would be 20°, for the influence of the Gulf stream does not reach us, and New Hampshire had nothing to temper the severity of an aphelion winter.

Let us review. We have seen that, through the precession of the equinoxes, the northern hemisphere was in aphelion 12,000 years ago in winter, and, consequently, 3,000,000 of miles further from the sun than in our present winter; that the aphelion winter is eight days longer than the perihelion summer, a relative difference of sixteen days in winter from the present perihelion winter; that, according to the meteorologist Croll, the winter of that period would be 10° or 15° colder than the present, but here really it would be 20° colder, according to the law of inverse squares in matter of *direct* rays of heat.

It will be remembered that Sir John Herschel and M. Pouillet, the French *savant*, by different methods found absolute zero to be 461° nearly, and stella space to be 239° below the zero of our thermometer (F), from which it appears the difference between 461° and 239°, viz., 222°, of our heat is due to the stars. Now, adding 23°, the temperature of New Hampshire in winter, to 239°, we have 262° due to the direct heat of the sun. The aphelion distance of the sun being ninety-three millions, and the perihelion distance ninety millions, in round numbers, without taking into account our atmosphere, according to the law of inverse squares, the proportion $(93)^2 : (90)^2 \cdot\cdot 262°$ gives about 242° as the temperature of the aphelion winter, or 20° below the present. So taking the average winter temperature at 23° (it is 22.81° at Concord) at present, reduced by 20°, it gives a temperature of 3° above zero for the four winter months of that period.

Again: we have seen that the sun twelve thousand years ago went one degree further south, giving eight more of mid-winter days, and a relative difference of sixteen days from the present to be added to that aphelion winter with the accompanying meteorological conditions; from which I infer an additional reduction of at least 3° for the four winter months, making a temperature of zero for the aphelion winter.

Then, again: from the eccentricity being one half million of miles greater than now, the sun being more distant by that amount than now, I infer a reduction of 3° more for the winter months on that account. These estimates would give an average temperature of 3° below zero for the four, instead of three, as now, winter months. The annual temperature near the north pole, or, rather, as near as approached, is 5° above zero. We may have a faint idea of the climate of 3° below zero for a third of the year. The mean temperature for December, January, and February would be 26° below the present; and that of the four other months of winter, now about 40°, would be reduced at least 15°, and for the seven months, including winter, the average temperature could not be much above 10°. Now I think it plain in these estimates, not extravagant, that conditions of atmosphere would exist with the extra thirty-two days for winter that would reduce the temperature lower than I have here estimated. Considering the effect of a summer sun upon such an icy atmosphere and an icy surface, I can have no doubt the temperature of summer, although the sun was 3,500,000 of miles nearer than in the winter, must, through evaporation, condensing clouds, winds, and the general meteorological conditions consequent, have been reduced during those months much below the present temperature of summer, and left the winter mantle of snow on the ground for the whole year, increasing from year to year until it exceeded the altitude of our highest mountains. No astronomer until Croll conceded that the eccentricity would have caused the icy climate necessary to produce the glacier; and none before him took into consideration the meteorological effects of such a winter upon the following summer.

While I believe these glacial conditions extended south to the Ohio, we must perhaps go back to those periods of greater eccentricity in aphelion winters to account for most of the phenomena of drift and boulders in this country as well as in Europe. But it is evident the precession period, which came once in 21,000 years, then, as now, was a part in producing the phenomena of those times.

But we have corroborative evidence of our position in the soil itself. In the precession period of 21,000 years, we must give a small half of it to a temperature fit for vegetation; and for vegetation of the present kind, we have a right to claim one third of the period; and it is evident that we have advanced more than half of the 7,000 years, or period of vegetation, in our state.

Soil is composed of the materials of disintegrated rocks, with decayed vegetable matter. Now fifteen inches is a sufficient estimate of the average depth to which vegetable matter can be traced in our soil, formed in place, not alluvial or drift. I will concede, though it is too small, an increment of .005 of an inch annually to the soil by vegetation. In a hundred years it would be half an inch, and in a thousand years five inches, and in three thousand years fifteen inches,—due to vegetable matter alone. We cannot, I think, in New Hampshire, give a greater age than that to vegetation of the present kind, even if so long. Our denuded hills then show us that three thousand years is sufficient time to account for all present vegetable growth in New Hampshire, since they escaped the erosive action of the ice sheet and glacier.

Let us digress here a moment, and turn to the future of a few hundred years. The sun is at the southern solstice the 21st of December, and at perihelion about the first of January, perihelion being about 10° on the ecliptic from the solstice. About

1250, as we have said, the winter solstice and perihelion were at the same point on the ecliptic. If we take that as the starting-point in the ecliptic, in 10,500 years from that time, or in the year 11,750, the aphelion winter will again come. We have then already passed 634 years towards it. Dividing 3,000,000, the present eccentricity, by one half of the period, viz., 10,500, we see we are going from the sun about 300 miles annually, and our climate is beginning to grow colder, and in about 10,000 years we shall reach the aphelion winter. We cannot then expect permanent improvement in our winters, since the sun is receding, and the cold will be perceptibly increased as time moves on; and the glare of the sun in summer will be proportionally increased in our latitude, but accompanied by denser clouds.

It is fortunate for us that we live in a perihelion winter in the middle of the precession period. We may lament for our successors,—of course we do for those of 10,000 years hence,—but the approach of the age of ice will be slow; they will have ample notice; the equator will then be but a few days distant, and long before the time the ice age shall set in they will move in crowds to the south, their descendants perhaps in ages to return.

Can you erect a monument that will resist the ravages of time and its accompanying destroying forces, to tell the future of 20,000 years of the race now inhabiting New Hampshire? All here now will, if anything, be fossil; and some geologist may trace out an ancient people from our cemeteries, as we do now from our Western mound-builders.

So much for our argument on temperature. In our study of the past conditions of climate we find a period, some twelve thousand years ago, where the temperature was cold enough to have caused constant congelation, and to have so continued many years; and we will now look to the product of those times,—the glacier. But how will we construct the glacier? To form an ice field, with a snow and ice covering several thousand feet thick, is very easy in the temperature we have reached.

Bordering on the Stekin river, in the southern part of Alaska, on the parallel of 57°, in July, 1875, a gentleman informs me he saw a glacier one thousand feet thick and a mile wide, extending far back into the mountains.

On Mt. Rainer, Washington territory, there are glaciers which are described by a traveller as more beautiful than those of the Alps. This is in latitude of 47°, a parallel less than three hundred miles north of ours.

To southern Greenland it is only a little further than to Chicago; and now let us bring Greenland down twelve hundred miles, and construct such conditions. The annual rain-fall here is forty-five inches: freezing it would be forty-eight inches (water expands in freezing), four feet. In a hundred years it would be four hundred feet, in a thousand years four thousand feet, and in two thousand years eight thousand feet, if not melting. If falling in snow, and we allow ten inches of snow for each inch of water, we have of the forty-eight inches of water four hundred and eighty inches or forty feet a year; in a thousand years forty thousand feet of snow, or an altitude, if not reduced by melting or pressure, of seven and one half miles or more. But we must suppose these conditions came by degrees, and it may have required six or eight thousand years. We have, then, all the elements and the factors of the snow mantle of enormous thickness,—the temperature, the snow, the ice, mountains, and ravines for the glacier.

What a dreary waste to contemplate! No vegetation, no bird or beast but those that live around the poles, which may have wandered here on the coast. Greenland to-day gives us an idea of such a condition, and we have only to travel north twelve hundred miles to reach a latitude of eternal snow. Greenland is represented to be an unexplored continent, buried under a "continuous and colossal mass of ice" that is moving slowly to the west to the sea.

This covering of snow and ice is by some estimated to be 4,000 feet thick, extending over an area of 1,000 miles long and 500 miles wide. When this moving mass reaches the coast it finds the ravines, and moves down as so many glaciers into the ocean, from 1,000 to 1,500 feet thick, carrying fragments of rocks and earth heaped upon it and frozen in it. And when far enough in the water to find a depth to swim, these glaciers break off into icebergs, and then, at the mercy of the sea, float down in some instances to our latitude.

Dr. Hayes and his party travelled some seventy miles in the interior of Greenland, and he beautifully describes his visit as follows: "Our station at camp was sublime as it was dangerous. We had attained an altitude of 5,000 feet above the sea-level, and were seventy miles from the coast, in the midst of a vast frozen Sahara immeasurable to the human eye. There was neither hill, mountain, nor gorge anywhere in view. We had completely sunk the strip of land between the Mer de Glace and the sea, and no object met the eye but our feeble tent, which bent to the storm. Fitful clouds swept over the face of the full-orbed moon, which descending towards the horizon glimmered through the drifting snow that scudded over the icy plain, to the eye in undulating lines of downy softness, to the flesh in showers of piercing darts."

The French exploring expedition in the Astrolobe found an iceberg from 100 to 225 feet above water, and about five miles in length.

These are the productions, these are the conditions, we have found in New Hampshire a few thousand years ago. The movements of glaciers are known, and are described with accuracy. The Alps are studied, and the glaciers are the admiration as well as the wonder of the world, and from them the laws of the glacier applied to other similar phenomena that were unexplainable otherwise. These glaciers are not solid, compact ice throughout, but composed of every form of ice and snow, from the freezing to the frozen, from the minute particle to the massive block, from the round to the angular. They move slowly, owing to obstructions in their way,—a few feet perhaps in winter, but in summer more. Now in giving motion to the glacier we have only to apply the same cause that acts upon all bodies of ice, gravitation. If a solid mass of ice, its motion downward must be very slow if it has any; but the glacier in motion is not entirely of that description. We may suppose a glacier in a ravine; the effect of melting the surface would be to create a current, and the water with the particles of ice would flow down the surface till intercepted, or drop down to the bottom through some crevice and create a muddy stream there. But in the melting of those parts of the ice that were obstructed there would be no obstacle in the way, and the whole mass would move onward and downward by its own gravity. If the ice be what we call in spring " soft," it would flow gently and constantly. The height of Mt. Washington is some 6,300 feet above the sea, or about an average of sixty feet to the mile. The running of water is quite perceptible with the fall of one inch a mile ; and, applying the alternate heat and cold to the glacier, alternate freezing and thawing of portions of it, though slower, yet its own gravity must give it motion downward. We may see this principle in every thaw in the spring in some sudden melting of snow and ice ; but raise these masses to immense proportions, and we have the work and movement of the glacier.

We may suppose this covering of snow and ice upon the plain of the Winnipiseogee, land-locked, hedged in by the Red Hills, Mounts Ossipee, Major, Gunstock, the Belknap hills, and other lofty hills upon every side, upon a plain twenty miles long and as many wide, and this at the close of a glacial age. The ice could not move *en masse*, and the only alternative nature gives is to dissolve the ice and let it pass off in another form. Much water from the dissolving mass will run over it, but most of it will run down the edges at the hillsides and under it, and some will find a crevice and bore through to the ground. The immense weight will press the ice deep into the thawing ground, and the percolating water will follow to reflow, charged with mud and clay, and flow off in the current.

It is the work of periods, not of a year or a hundred years ;— but time is limitless to our mathematics, and this work requires only a division of time. As Lake Geneva was scooped out by the ice, so Lake Winnipiseogee was formed by the process of erosion, in the work of water and ice. So the Massabesic was dug out, and the sand, the clay, and the mud from these reservoirs,—the Winnipiseogee and others to the north,—were carried down by the currents of the river, and now form the terraces and banks of the Merrimack.

In the formation of river terraces all agree they are in part the work of erosion of an older formation. There are also sedimentary aggregations from erosions in other parts. At Hooksett falls there is the tearing away of an old barrier, a ridge that once extended from the Pinnacle across the river to the bluffs near, an obstruction of high elevation, with falls higher and grander than the Montmorenci of to-day—a reservoir flowing back beyond Concord and receiving the muddy torrents laden with clay from the lakes to the north, to be deposited on the eastern shore, now so useful in business along the river. At the Amoskeag falls there are the remnants of an ancient cliff extending across the river, now worn down, but once high enough to flow the water over the intervening banks to Hooksett.

If there were an obstruction below Manchester of sufficient height (I think there must have been such) there would have been standing water on the plain of Manchester. In times of flood strong currents would flow through, with their pools and eddies on either side, flowing and reflowing and depositing the sand in its control, until the sand plain formed was left dry, upon which Manchester stands.

The picture of the ancient Merrimack would be beautiful indeed. Here a lakelet extending from Goff's falls to the higher Amoskeag, winding up the Piscataquog, and from the Amoskeag to the cataract at Hooksett,—thence north to Concord, and beyond, flowing the low lands adjoining,—a river of lakelets from a few rods to several miles in width, uniting only in falls or cataracts.

The clay came down in the muddy streams, as the rocks yielded to the disintegrating forces of alternate heat and frosts, when the curtain of the aphelion winter began to rise, and was gently deposited, little by little,—the sand, more sluggish in its course, following slowly behind,—while the huge boulder I have named floated down on the ice from the Epsom hills, and became stranded on the clay banks at Suncook.

We know that soil found upon the hillside is the decomposition of the older rocks there, with the addition of vegetable matter washed there, or blown there by the winds; and we know further, that some of this soil finds its way to the running stream, while the sides of the hill are left bare and rocky. The clay passes off in the stream in the form of mud, while the sand moves sluggishly; but if only a few feet a year, in a hundred and a thousand years the movement is mighty.

Our rocks are chiefly granite, gneiss, quartz, mica, feldspar, and sandstone of various kinds, and all have sand and clay in certain proportions. A hundred tons of quartz decomposed would make as many tons of sand. In a hundred tons of feldspar, most easily decomposed by water and frosts, there would be $65\frac{1}{4}$ tons of sand, $18\frac{1}{4}$ tons of clay, and $14\frac{2}{3}$ tons of potash; and in a hundred tons of mica there would be $46\frac{1}{3}$ tons of sand, $36\frac{3}{4}$ tons of clay, $4\frac{1}{2}$ tons of iron, and $9\frac{1}{5}$ tons of potash, with other materials. Such are the proportions substantially as given by Lyell. So we have abundance of sand and clay in the decomposition of the rocks. Both move away from the parent rock; but clay moves so far and is so transformed as to have no resemblance to the family rock. These disintegrated rocks from lake and mountain, in the form of mud and sand, are the materials of which the Merrimack built its banks and terraces.

As we began with a view of the Merrimack river, its terraces, its banks of sand and clay, its boulders, its worn and torn down obstructions, in our study thereof we trace back to an age of cold, of snow and ice in glacial form, freezing, and bringing down the boulders, thawing again and bringing down the sand and clay, flowing and reflowing, forming banks and terraces, and channelling through the rocks, a cañon whose running waters give employment to thousands now, and hereafter will furnish labor and employment to millions more to come.